SECONDARY STRESSES IN BRIDGES

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Secondary Stresses in Bridges

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Introduction

The expression Secondary Stresses originated with Professor Asimont of the Polytechnic School in Munich Bavaria. In a paper "Primary and Secondary Stresses", which was published in 1880 in Zeitschrift fur Baukunde,Asimont discusses the effects of eccentric loading on a column, and here made the distinction between primary or direct stress and that due to a couple producing a bending stress which he called secondary. But long before Asimont coined that expression, engineers considered secondary stresses in their designs.

The subject of Secondary Stresses being one of importance, the Polytechnic School in Munich, in the year 1877, offered a prize on the solution of the problem of how to calculate these stresses in riveted trusses. In formulating the problem, Asimont suggested that, owing to the fact that the lines of the resulting stresses no longer pass through the center of panel points, its solution might be effected by the employment of Euler's equation of the Elastic Line. The prize was award-

ed to Manderla, in 1879, whose excellent solution is found in a highly scientific and mathematical paper, published in 1880, in Allgemeine Bauzeitung, under the title "The Calculation of Secondary Stresses which occur in Simple Trusses as a consequence of Rigid Joints". Although Manderla's solution was a very great step forward, the problem in all its aspect has not yet been completely solved.

Before the appearance of Manderla's solution, Engerser had published an approximate method. In the year 1881, the late Professor Winkler gave a lecture on Secondary Stresses before an organization of Engineers and Architects in Berlin, in which he said that for some years past he had paid attention to the subject. This lecture is published in Deutsche Bauzeitung in 1881, under the title "Secondary Stresses in Iron Construction". In 1885 Professor Landsberg contributed a graphical solution under the assumption that the chords alone are riveted; and in 1886 Professor Miiller-

Breslaw made an analytical contribution. Professor Ritter in 1890, gave a graphical solution, and in the year 1892-93, Professor Engesser published a book on "Secondary Stresses".

Professor Mohr contributed in 1892 an analytical method which can be found in his valuable book "Alhandlungen and dern Gebrete der Technishen Mechanik", published in 1906, in which he treats in a masterly manner subjects appertaining to technical mechanics.

The fundamental truths and the methods of calculations that came to light in studying this problem we owe to Germans.

Acknowledgment

Truly appreciative of the manifest interest and efforts taken in our behalf, we take this opportunity to express our thanks to Mr. John C. Penn, Associate Professor in Civil Engineering, Armour Institute of Technology, for his valuable assistance.

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SECONDARY STRESSES IN BRIDGES

In the determination of stresses in a truss the following assumptions are made:

(1) All members of a truss are free to turn at the joints, i.e. they are connected at the joints by frictionless pins about which the members are free to turn.

(2) The first assumption is the basis of the second: Since the members are free to turn at the joints, the former remain straight after applications of loads, when a change in relative position of the joints takes place.

There are other assumptions made (like: joints lie in the gravity axes of the members; all external loads and weight of members are applied at the joints only) with which we are not concerned in the present discussion.

The stresses resulting from an analysis based on these assumptions are called "Primary Stresses".

The stresses resulting from an analysis which considers the effects of not having all these as-

sumed conditions realized are called "Secondary Stresses".

That members are not free to turn at the joints is true even about pin connections, because there is always friction between the member and the pin, while in riveted connections that freedom to move is inconceivable.

The members, therefore, do not remain straight after loads are applied, and a change in relative position of the joints brings about a single or double bending in the member. The stresses in the various members of a truss resulting from bending due to rigidity of the joint connections are the "Secondary Stresses".

To summarize the existing methods of determination of secondary stresses and to represent them so as to enable the practical designer to apply them quickly and effectively is the aim of the present discussion.

CALCULATION OF THE CHANGES OF ANGLE IN ANY TRIANGLE IN TERMS OF THE CHANGES IN THE LENGTHS OF THE MEMBERS

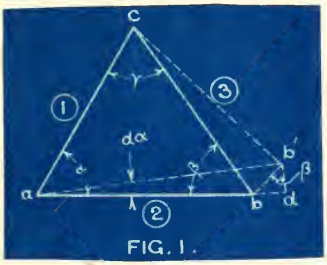

FIG. 1.

Let a b c be the original form of triangle in Fig. 1.

S_1, S_2, S_3 = stress intensity in each member.

l_1, l_2, l_3 = length of each member.

E = modulus of elasticity.

Assume that a b will lengthen after application of loads. By definition unit deformation = $\frac{S}{E}$.

Total deformation = $\frac{sl}{E}$

The elongation in a b = $\frac{s_2 l_2}{E}$ = bd

Assuming a c fixed, b will move to new position b'. a b' = a d and b'd as a small arc along which d moves to b' may be considered perpendicular to a b. bc = b'c and for an analogous reason bb' is perpendicular to bc. Therefore, $\angle$ a b c = (β) = bb'd.

$$d\alpha = \frac{b'd}{ad} = -\frac{b'd}{l_2} \quad \text{(in radians)}$$

But $b'd = bd$, $\cot\beta = \frac{s_2 l_2 \cot\beta}{E}$

$$\therefore d\alpha = -\frac{s_2 \cot\beta}{E} \qquad (1)$$

To find the change in the angle α due to the shortening of a c assume a b fixed.

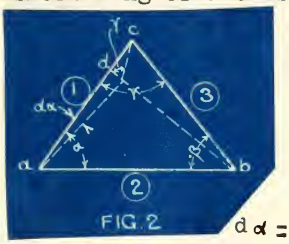

FIG. 2

$ad = ac'$ and $c'd$ is perpendicular to ac; $bc = bc'$ and $c'c$ is perpendicular to bc.

$\therefore \angle dc'c = \angle\gamma$

$$d\alpha = \frac{c'd}{l_1} \quad \text{(in radians)}$$

But $c'd = dc \cot\gamma$

$$dc = \frac{s_1 l_1}{E}$$

$$\therefore c'd = \frac{s_1 l_1 \cot\gamma}{E}$$

$$\text{and } d\alpha = -\frac{S_1 \cot\gamma}{E} \qquad (2)$$

To find the change in the angle α due to the lengthening of bc assume ab fixed.

$$ce = \text{elongation} = \frac{s_3 l_3}{E}$$

FIG. 3

be = bc' $\therefore$ c'e is perpendicular to be.

ac' = ac $\therefore$ c'c is perpendicular to ac $\therefore \angle$ ec'c = γ

$d\alpha = \frac{c'c}{ac}$ (in radians)

$$\frac{ce}{cc'} = \sin\gamma \quad \therefore \quad cc_1 = \frac{ce}{\sin\gamma}$$

$$\therefore \quad d\alpha = \frac{ce}{ac \sin\gamma} = \frac{s_3 l_3}{ac \sin\gamma E}$$

$ac \sin\gamma = ak.$

$ck = ak \cot\gamma$)
$kb = ak \cot\beta$) $bc = ak(\cot\beta + \cot\gamma)$

$$\therefore \quad ak = \frac{bc}{(\cot\beta + \cot\gamma)}$$

$$\therefore \quad ac \sin\gamma = \frac{bc}{\cot\beta + \cot\gamma}$$

$$d\alpha = \frac{s_3 l_3}{ac \sin\gamma E} = \frac{S_3}{E}(\cot\beta + \cot\gamma) \qquad (3)$$

Adding up equations (1), (2) and (3) we get the total change in α corresponding to the deformations of all three sides of the triangle.

$$\text{Total } d\alpha = \frac{s_2 \cot\beta}{E} - \frac{s_1 \cot\gamma}{E} + \frac{s_3(\cot\beta + \cot\gamma)}{E}$$

$$= -\frac{s_1 \cot\gamma - s_2 \cot\beta + s_3 \cot\beta + s_3 \cot\gamma}{E}$$

$$= \frac{s_3 - s_2}{E} \cot\beta + \frac{s_3 - s_1}{E} \cot\gamma \qquad (4)$$

Likewise: $$d\beta = \frac{s_1 - s_3}{E} \cot\gamma + \frac{s_1 - s_2}{E} \cot\alpha \qquad (5)$$

$$d\gamma = \frac{s_2 - s_1}{E} \cot\alpha + \frac{s_2 - s_3}{E} \cot\beta \qquad (6)$$

Stating in words:

In each case the numerator is the value of s for the side opposite minus that of the adjacent times the cotangent of the included angle.

Since the sum of angles of a triangle remains 180° after deformation:

$$d\alpha + d\beta + d\gamma = 0 \qquad (7)$$

which serves as a convenient check in the computations.

THE DEFLECTION ANGLES OF A BEAM SUBJECTED TO GIVEN MOMENTS APPLIED AT THE TWO ENDS

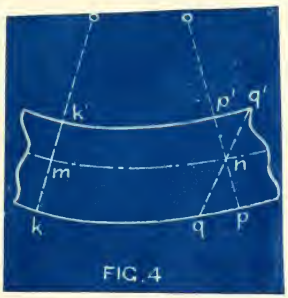

FIG.4

Let mn be any short length measured along the neutral surface of a beam. Let kk' and pp' be two normal sections passing thru m and n. Before bending kk' and pp' were parallel; after the bending they intersect at o, the center of curvature. Let qq' be drawn through n parallel to kk'. Then qp represents the elongation of the fiber kq and q'p' the shortening of the fiber k'q', and these changes in length are proportional to their distances from the neutral surface. Let the change of length qp be called e and let s be the corresponding unit stress on fiber kp, and E the modulus of elasticity of the material. Let the length of the beam be l and the short distance mn be dl. Then the value of qp is $e = \frac{sdl}{E}$.

Now let c be the distance from qp to the neutral surface of the beam, and let R be the radius

of curvature of the elastic curve.

From similar figures o mn and pnq it follows that $\frac{om}{mn} = \frac{nq}{qp}$ or $\frac{R}{dl} = \frac{c}{e}$

and inserting for e its value $\frac{s}{E}dl$, this becomes

$$\frac{s}{e} = \frac{E}{R}$$

But the flexure formula gives

$\frac{s}{c} = \frac{M}{I}$, where M is the bending moment of the external forces and I is the moment of inertia of the section area. Accordingly

$$MR = EI \text{ or } R = \frac{EI}{M}$$

which gives the relation between the radius of curvature of the elastic curve at any section and the bending moment at that section.

But from differential calculus (see Townsend and Goodenough page 158) $R = \frac{dl^3}{dxd^2y}$

If this value of R be equated to $\frac{EI}{M}$, there results a general differential equation of the elastic curve which applies to the flexure of all beams or arches ~~xxxxxx~~ in which the elastic limit

of the material is not exceeded.

Since the length of a small part of a beam does not materially differ from its horizontal projection, the length dl may be placed equal to dx and $\frac{d^2y}{dx^2} = \frac{M}{EI}$ or $\frac{EI\ d^2y}{dx^2} = M$, which is the differential equation of the elastic deflection of beams.

In order to find the deflection at any point of a beam we must integrate the last equation twice:

$$\frac{dy}{dx} = \frac{Mx}{EI} \quad \text{or} \quad dy = \frac{M}{EI}\ xdx$$

$$\therefore\ y = \int \frac{M}{EI}\ xdx \qquad (8)$$

Now consider the beam AB subjected to the moments M_1 and M_2 and shears V_1 and V_2, but sustaining no intermediate loads as the case would be with a member of truss to which stresses are transmitted through floor beams at the joints only.

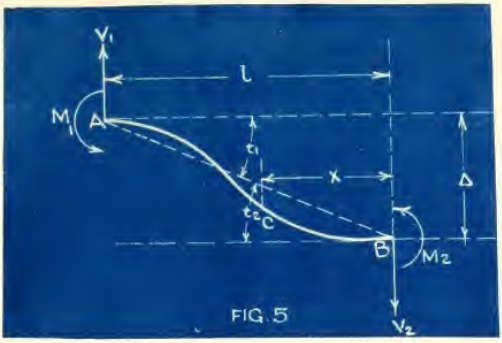

FIG. 5

Assume a counter counter clockwise direction of moments to be positive.

Taking moments about B

$$\Sigma M_B = o \quad M_1 + M_2 + V_1 l = o \therefore V_1 = \frac{M_1 + M_2}{l}$$

Taking moments about A

$$\Sigma M_A = o \quad M_1 + M_2 + V_2 l = o \therefore V_2 = \frac{M_1 + M_2}{l}$$

At any point C distant x from B, the bending moment is $M_x = M_2 - V_2 x = M_2 - \frac{(M_1 + M_2)}{l} x$

The deflection Δ at B with respect to the tangent at A, considered as positive downward is from equation (8) equal to $\int_B^A \frac{Mxdx}{EI}$ or

$$\Delta = \frac{1}{EI} \int_o^l \left[M_2 x - (M_1 + M_2) \frac{x^2}{l} \right] dx$$

$$= \frac{l^2}{6EI} (2 M_1 - M_2)$$

The value of the deflection angle $t_1 = \frac{\Delta}{l}$ (in radians) $\therefore$ $t_1 = \frac{1}{6EI}(2 M_1 - M_2)$ (9)

Likewise:

$$t_2 = \frac{1}{6EI}(2 M_2 - M_1) \qquad (10)$$

The last equations solved for M_1 and M_2 in terms of t_1 and t_2 give:

$$M_1 = \frac{2EI}{l}(2 t_1 + t_2) \qquad (11)$$

$$M_2 = \frac{2EI}{l}(2 t_2 + t_1) \qquad (12)$$

Notation and conventional scheme for signs. It will be assumed that distortions of the members of triangle are as shown in the figure 6. Since the tangent at each joint has a counter clockwise rotation, the bending moments are all positive. The values of t are also to be considered positive.

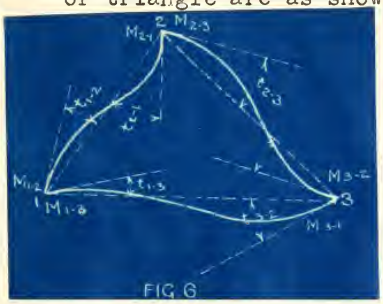

FIG. 6

$I_{1-2} = I_{2-1}$ = moment of inertia of 1-2

t_{1-2} = deflection angle at 1 of 1-2 and

t_{2-1} = deflection angle of 2 at 2-1 c.t.c.

VALUES OF THE DEFLECTION ANGLES t IN TERMS OF THE CHANGES OF ANGLE dα etc.

Consider any joint n of any structure, and let the straight lines n-1, n-2, n-3 etc. represent the lines joining the several joints after distortion. The full lines show the bent forms of the several members. The angle t_{n-1}, t_{n-2}, t_{n-3} and t_{n-4} represent the deflection angles of the several members at joint n. Let α_1, α_2, α_3 be the original angles between the members. After distortion the angles between the straight lines joining the apexes will be respectively $\alpha_1 + d\alpha_1$, $\alpha_2 + d\alpha_2$, and $\alpha_3 + d\alpha_3$.

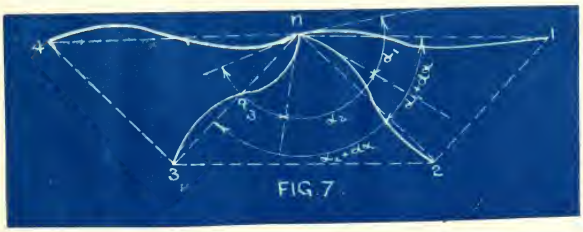

FIG.7

Then if we select one of the deflection angles as a reference angle, we may express the other values of t at joint n in terms of t_{n-1}, and the changes of angle $d\alpha_1$.

From the figure: $\alpha_1 + d\alpha_1 + t_{n-1} = \alpha_1 + t_{n-2}$

$$\therefore\ t_{n-2} = t_{n-1} + d\alpha_1$$

Similarly $t_{n-3} = t_{n-1} + d\alpha_1 + d\alpha_2$

" $t_{n-4} = t_{n-1} + d\alpha_1 + d\alpha_2 + d\alpha_3$

In general we may write

$$t_{nm} = t_{n-1} + \sum_1^m d\alpha \qquad (13)$$

SELECTION OF THE REFERENCE DELFECTION ANGLE

It is convenient at each joint to select one deflection angle as a reference angle and to express other deflection angles at this joint in terms of it and the changes of angle d .

In the sketches of the truss which follow the reference angle is taken the first angle which we encounter standing on the outside of truss and going around in a clockwise direction. They are indicated at T_1, T_2, T_3 etc.

THE MOMENTS AT ANY JOINT IN TERMS OF THE DEFLECTION ANGLE

Since the truss is in equilibrium the sum of the bending moments at ends of members intersecting at any joint equals zero.

Thus in Fig.

$$M_{n1} + M_{n2} + M_{n3} + M_{n4} = 0 \qquad (14)$$

Expressing these moments in terms of several deflection angles t as in eq.

$$\frac{2\,El_{n1}}{l_{n1}}\,(2\,t_{n1} + t_{1n}) + \frac{2\,El_{n2}}{l_{n2}}\,(2\,t_{n2} + t_{2n}) + \frac{2\,El_{n3}}{l_{n3}}$$

$$(2\,t_{n3} + t_{3n}) + \frac{2\,El_{n4}}{l_{n4}}\,(2\,t_{n4} + t_{4n}) = 0 \qquad (15)$$

A similar equation may be written out for each joint, thus giving as many equations as there are joints. In the many different equations will then appear as many different deflection angles "t" as there are joints. These equations can be solved simultaneously. Each value of t can be substituted back in the general equation of the bending moment for each member as in equation 11 or 12.

$$M_{nm} = \frac{2\,El}{l}\,(2\,t_{nm} + t_{mn}) \qquad (16)$$

Each term of equation 15 contains I. For convenience let it be called **K**. Then equation 15 after dividing by 2 E each of the terms becomes:

$$K_{n1}\ (2\ t_{n1} + t_{1n}) + K_{n2}\ (2\ t_{n2} + t_{2n}) = o \qquad (17)$$

or $2(K_{n1}\ t_{n1} + K_{n2}\ t_{n2} + \text{etc.}) + K_{1n}\ t_{1n} + K_{2n}\ t_{2n} + = o.$

FIBRE STRESS IN TERMS OF t

The stress in the outside fiber of a member in bending is:

$$f = \frac{Mc}{I} \qquad (18)$$

Substituting in the last equation the value of M as in equation 16, we get

$$f_{nm} = \frac{2\ Ec}{l}\ (2\ t_{nm} + t_{mn}) \qquad (19)$$

which is the final equation used in finding the secondary stress of any member in a truss.

FORMULATION OF EQUATION

The General Equation is:

$$2(K_{n-1}T_{n-1} + K_{n-2}T_{n-2} + \cdots)\, K_{1-n}T_{1-n}K_{2-n}T_{2-n} + \cdots = 0.$$

The following equations are worked out in connection with Table C 1, Case 1.

For Joint (1)

$$2(K_{1-2}T_{1-2} + K_{1-3}T_{1-3}) + K_{2-1}T_{2-1} + K_{3-1}T_{3-1} = 0.$$

$2\ KT = 2(25.85\ T_1 + 146.6) = 51.7\ T_1 + 293.2$

$K_{2-1}T_{2-1} = 10.55\ T_2$

$K_{3-1}T_{3-1} = 15.3\ T_3 - 281$

$$51.7\ T_1 + 10.55\ T_2 + 15.3\ T_3 = -12.2 \qquad (1)$$

Joint (2)

$$2(K_{2-1}T_{2-1} + K_{2-3}T_{2-3} + K_{2-4}T_{2-4}) + K_{1-2}T_{1-2} + K_{3-2}T_{3-2} + K_{4-2}\ T_{4-2} = 0.$$

Joint (2) - continued.

$2\ KT = 2(21.53\ T_2 - 291 - 23.6) = 43.06\ T_2 - 582 - 47.2$

$K_{1-2}T_{1-2} = 10.55\ T_1 + 146.6$

$K_{3-2}T_{3-2} = .434T_3 - 25.7$

$K_{4-2}T_{4-2} = 10.55\ T_4$

$$10.55\ T_1 + 43.06\ T_2 + .434\ T_3 + 10.55\ T_4 = +508.3 \quad (2)$$

Joint (3)

$$2(K_{3-5}T_{3-5} + K_{3-4}T_{3-4} + K_{3-2}T_{3-2} + K_{3-1}T_{3-1}) + K_{5-3}T_{5-3} + K_{4-3}T_{4-3} + K_{2-3}T_{2-3} + K_{1-3}T_{1-3} = 0.$$

$2\ KT = 2(37.21\ T_3 - 366.7)$

$K_{5-3}T_{5-3} = 20.3\ T_5 + 1820$

$K_{4-3}T_{4-3} = 1.18T_4 - 22.7$

$K_{2-3}T_{2-3} = .434\ T_2 - 23.6$

$K_{1-3}\ T_{1-3} = 15.3\ T_1$

$$15.3\ T_1 + .434\ T_2 + 74.42\ T_3 + 1.18\ T_4 + 20.3\ T_5 = -1039.7 \quad (3)$$

Joint(4)

$$2\ (K_{4-2}T_{4-2} + K_{4-3}T_{4-3} + K_{4-5}T_{4-5} + K_{4-6}T_{4-6}) + K_{2-4}T_{2-4} + K_{3-4}T_{3-4} + K_{5-4}T_{5-4} + K_{6-4}T_{6-4} = 0.$$

Joint (4) - continued.

$2 \quad KT = 54.48\ T_4 - 188$

$K_{2-4}T_{2-4} = 10.55\ T_2 - 291.0$

$K_{3-4}T_{3-4} = 1.18\ T_3 - 60.3$

$K_{5-4}T_{5-4} = 1.71\ T_5 - 27.8$

$K_{6-4}T_{6-4} = 13.8\ T_6$

$$10.55\ T_2 + 1.18\ T_3 + 54.48 T_4 + 1.71 T_5 + 13.8 T_6 = +567.1 \quad (4)$$

Joint (5)

$$2(K_{5-7}T_{5-7} + K_{5-6}T_{5-6} + K_{5-4}T_{5-4} + K_{5-3}T_{5-3}) +$$
$$K_{7-5}T_{7-5} + K_{6-5}T_{6-5} + K_{4-5}T_{4-5} + K_{3-5}T_{3-5} = 0.$$

$2 \quad KT = 2(42.99T_5 + 1792.31) = 85.98T_5 + 3584.62$

$K_{7-5}T_{7-5} = 20.3\ T_7 + 4190$

$K_{6-5}T_{6-5} = 0.675T_6 - 41.6$

$K_{4-5}T_{4-5} = 1.71\ T_4 - 126.5$

$K_{3-5}T_{3-5} = 20.3\ T_3$

$$20.3T_3 + 1.71T_4 + 85.98T_5 + 0.675\ T_6 + 20.3T_7 = 7606.52 \quad (5)$$

Joint (6)

$$2(K_{6-4}T_{6-4} + K_{6-5}T_{6-5} + K_{6-7}T_{6-7} + K_{6-8}T_{6-8}) +$$
$$K_{4-6}T_{4-6} + K_{5-6}T_{5-6} + K_{7-6}T_{7-6} + K_{8-6}T_{8-6} = 0.$$

Joint (6) - continued.

$2\ KT = 2\ (29.98T_6 + 4502.1) = 59.96T_6 - 9004.2$

$K_{4-6}T_{4-6} = 13.8\ T_4 + 55.2$

$K_{5-6}T_{5-6} = 0.675T_5 + .11$

$K_{7-6}T_{7-6} = 0.936T_7 + 120.$

$K_{8-6}T_{8-6} = 14.57\ T_8$

$13.8T_4 + 0.675T_5 + 59.96T_6 + 0.936T_7 + 14.57T_8 = +8832.1 \quad (6)$

Joint (7)

$2(KT_{7-9} + KT_{7-8} + KT_{7-6} + KT_{7-5}) +$

$KT_{9-7} + K_{8-7}T_{8-7} + K_{6-7}T_{6-7} + K_{5-7}T_{5-7} = 0.$

$2\ KT = 2(41.72\ T_7 + 4316.87) = 83.44\ T_7 + 8633.74$

$K_{9-7}T_{9-7} = 20.3\ T_9 + 238.$

$K_{8-7}T_{8-7} = 0.18T_8 + 12.25$

$K_{6-7}T_{6-7} = 0.936T_6 - 130.5$

$K_{5-7}T_{5-7} = 20.3\ T_5$

$20.3T_5 + 0.936T_6 + 83.44T_7 + 0.18T_8 + 20.3T_9 = -8753.49 \quad (7)$

Joint (8)

$2\ (K_{8-6}T_{8-6} + K_{8-7}T_{8-7} + K_{8-9}T_{8-9} + K_{8-11}T_{8-11} + K_{8-10}T_{8-10})$

$+ K_{6-8}T_{6-8} + K_{7-8}T_{7-8} + K_{9-8}T_{9-8} + K_{11-8}T_{11-8} + K_{10-8}T_{10-8} = 0.$

Joint (8) - continued.

$2\ KT = 2(30.16\ T_8 + 50.15) = 60.32\ T_8 + 100.3$

$K_{6-8}T_{6-8} = 14.57\ T_6 - 4330.$

$K_{7-8}T_{7-8} = 0.18\ T_7 + 6.87$

$K_{9-8}T_{9-8} = 0.936T_9 + 75.2$

$K_{11-8}T_{11-8} = .675T_{11} + 45.4$

$K_{10-8}T_{10-8} = 13.8\ T_{10}$

$14.57T_6 + 0.18T_7 + 60.32T_8 + 0.936T_9 + 13.8T_{10} + 0.675T_{11}$

$= + 4102.23 \qquad (8)$

Joint (9)

$2(K_{9-11}T_{9-11} + K_{9-8}T_{9-8} + K_{9-7}T_{9-7}) +$

$K_{11-9}T_{11-9} + K_{8-9}T_{8-9} + K_{7-9}T_{7-9} = 0.$

$2\ KT = 2(41.54T_9 + 313.2) = 83.08T_9 + 626.4$

$K_{11-9}T_{11-9} = 20.3T_{11} + 920$

$K_{8-9}T_{8-9} = 0.936T_8 + 92.2$

$K_{7-9}T_{7-9} = 20.3\ T_7$

$20.3T_7 + 0.936T_8 + 83.08T_9 + 20.3T_{11} = - 1638.6 \qquad (9)$

Joint (10)

$2(K_{10-8}T_{10-8} + K_{10-11}T_{10-11} + K_{10-13}T_{10-13} + K_{10-12}T_{10-12})$

$+ K_{8-10}T_{8-10} + K_{11-10}T_{11-10} + K_{13-10}T_{13-10} + K_{12-10}T_{12-10}$

$= 0.$

(Joint (10) continued)

$2\ KT = 2(27.24T_{10} + 148) = 54.48T_{10} + 296.$

$K_{8-10}T_{8-10} = 13.8T_8 - 81.4$

$K_{11-10}T_{11-10} = 1.71T_{11} + 135$

$K_{13-10}T_{13-10} = 1.18T_{13} + 29.3$

$K_{12-10}T_{12-10} = 10.55\ T_{12}$

$13.8T_8 + 54.48T_{10} + 1.71T_{11} + 10.55T_{12} + 1.18T_{13} = -378.9 \quad (10)$

Joint (11)

$2(K_{11-13}T_{11-13} + K_{11-10}T_{11-10} + K_{11-8}T_{11-8} + K_{11-9}T_{11-9})$

$+ K_{13-11}T_{13-11} + K_{10-11}T_{10-11} + K_{8-11}T_{8-11} + K_{9-11}T_{9-11} = 0.$

$2\ KT = 2(42.98T_{11} + 1100.4) = 85.96T_{11} + 2200.8$

$K_{13-11}T_{13-11} = 20.3T_{13} - 272$

$K_{10-11}T_{10-11} = 1.71T_{10} + 99.0$

$K_{8-11}T_{8-11} = 0.675T_8 + 27.1$

$K_{9-11}T_{9-11} = 20.3T_9$

$0.675T_8 + 20.3T_9 + 1.71T_{10} + 85.96T_{11} + 20.3T_{13} = -2054.9 \quad (11)$

Joint (12)

$2(K_{12-10}T_{12-10} + K_{12-13}T_{12-13} + K_{12-14}T_{12-14})$

$+ K_{10-12}T_{10-12} + K_{13-12}T_{13-12} + K_{14-12}T_{14-12} = 0.$

Joint (12) - continued.

$2 \quad KT = 2(21.53T_{12} - 213.35) = 43.06T_{12} - 426.7$

$K_{10-12}T_{10-12} = 10.55T_{10} + 29.$

$K_{13-12}T_{13-12} = 0.434T_{13} + 13.25$

$K_{14-12}T_{14-12} = 10.55T_{14}$

$10.55T_{10} + 43.06T_{12} + 0.434T_{13} + 10.55T_{14} = + 384.45 \quad (12)$

Joint (13)

$2(K_{13-14}T_{13-14} + K_{13-12}T_{13-12} + K_{13-10}T_{13-10} + K_{13-11}T_{13-11})$

$+ K_{14-13}T_{14-13} + K_{12-13}T_{12-13} + K_{10-13}T_{10-13} + K_{11-13}T_{11-13}$

$= o.$

$2 \quad KT = 2(37.21T_{13} - 229.45) = 74.42T_{13} - 458.9$

$K_{14-13}T_{14-13} = 15.3T_{14} + 159.$

$K_{12-13}T_{12-13} = 0.434T_{12} + 8.65$

$K_{10-13}T_{10-13} = 1.18T_{10} + 20$

$K_{11-13}T_{11-13} = 20.3\ T_{11}$

$1.18T_{10} + 20.3T_{11} + 0.434T_{12} + 74.42T_{13} + 15.3T_{14} = +271.25 \quad (13)$

Joint (14)

$2(K_{14-12}T_{14-12} + K_{14-13}T_{14-13}) + K_{12-14}T_{12-14} + K_{13-14}T_{13-14})$

$= o.$

$2 \quad KT = (25.85T_{14} + 159)2 = 51.7T_{14} + 318$

$K_{12-14}T_{12-14} = 10.55\ T_{12} - 222$

$K_{13-14}T_{13-14} = 15.3\ T_{13}$

$10.55\ T_{12} + 15.3\ T_{13} + 51.7\ T_{14} = - 96 \quad (14)$

EXPLANATION OF THE TABLES

The determination of secondary stresses due to given loading in a member depends upon the solution of equation:

$$f_{nm} = \frac{2Ec}{t} (2\, t_{nm} + t_{mn})$$

This apparently simple equation requires nevertheless great care in arranging and tabulating the necessary steps in order to make the solution correct and systematic.

Table A is self explanatory since the date about the members making up the truss are simply recorded.

In tables B each triangular fragment of the truss is taken separately and the differential changes in the angles are found according to formulas 4,5,8,6.

In each case the check referred to on page 4 was obtained.

In tables C each joint was taken separately and for the purpose of solving equation (17) the K's and the differential angles were arranged and summed up as shown.

In Table D the equations for moments at each

joint were formulated according to equation (17) and terms containing unknown t's were kept on one side of the equation; absolute terms were kept on the other.

In Tables E the equations were solved by trial, since the exact method of solving the equations by elimination did not prove satisfactory.

In Table F the equation 19 is solved and recorded as shown, changing also the stress due to given joint load to that of 1000 lbs.

In Table G the maximum primary stress was compared with the secondary stress and the percentage of the latter to the former was found.

CONCLUSIONS

Studying the preceding equation we derive the following conclusion in relation to the secondary stresses which are as follows:

(1) The Secondary Stresses are in general proportional to the primary stresses and therefore are conveniently expressed in percentage of primary stresses.

(2) Other things being equal or similar, the percentages of secondary stresses are proportional to the distances from gravity axis to outer fibre in the plane of bending and inversely proportional to the lengths of members, i.e. when the members are symmetrical the secondary stresses are proportional to the ratios of width to length. Thus if two trusses are compared whose general dimensions and moments of inertia of members are proportional, but the ratio of width to length of the various members of one truss is in all cases twice this ratio in the other truss, then the percentage of the secondary stresses in the first truss will be twice the percentages in the second truss.

(3) The more uniform the proportions of a truss the less in general will be the secondary stresses. Trusses consisting of approximately equilateral triangles present the most uniform conditions and will have, in general, the lowest secondary stresses. Trusses consisting of right angle triangles will show somewhat higher secondary stresses, and such stresses will be large if the ratio of height to panel length is large.

The secondary stresses as treated in this thesis are those only due to the bending of members in the plane of the truss. There are secondary stresses, however, due to bending of members in a transverse plane on account of the deflection of the floor beams, to eccentric connections, and to the weight of the members themselves. The first secondary stresses are the most important, the latter ones tend to modify the first slightly, but it is beyond the scope of this thesis to deal with them.

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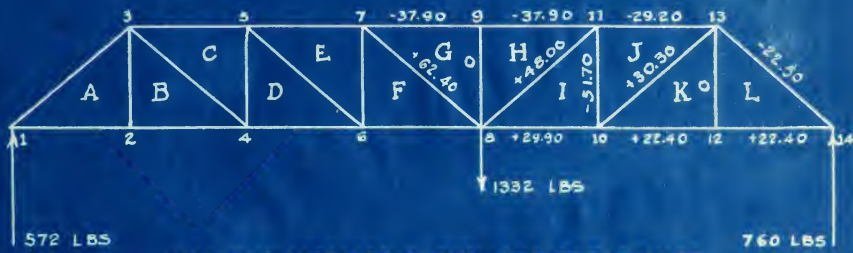
438 (3000 - W)

LOADING FOR CASE 1

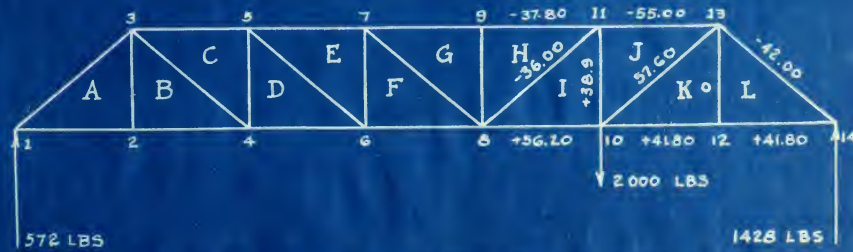
PRATT
PONY TRUSS
7 PANELS @ 17'-0" = 119'-0" HEIGHT = 14'-0"

LOADING FOR CASE 2



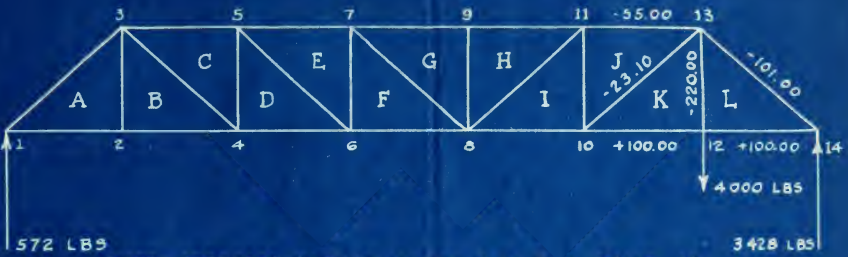
NOTE: THE STRESSES SHOWN ARE PER SQUARE INCH OF CROSS SECTION

LOADING FOR CASE 3



NOTE: STRESSES NOT INDICATED ARE THE SAME AS FOR STRESSES OF MEMBERS FOR PREVIOUS CASES.

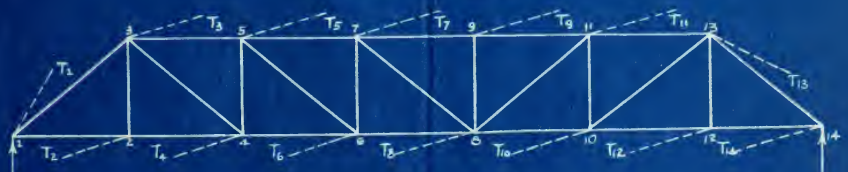
LOADING FOR CASE 4



NOTE: STRESSES NOT INDICATED ARE THE SAME AS FOR STRESSES OF MEMBERS FOR PREVIOUS CASES

STRESSES FOR UNIFORM LOADING

REFERENCE ANGLES



NOTE: THE VALUES ENTERED IN THE CALCULATIONS FOR LOADS AT 2, 4, AND 8, ARE THE SAME AS FOR LOADS AT 12, 10, AND 6, RESPECTIVELY WITH THE REFERENCE ANGLES PROPERLY PLACED.

Table A

Member	Section area sq. in.	Length Inches	I	c inches	$K = \frac{I}{L}$	$\frac{c}{I}$	Make up of Section
1-2	41.72	204	2148	10	10.55	.049	See "Pony Truss
2-4	41.72	204	2148	10	10.55	.049	"
4-6	61.86	204	2810	10	13.80	.049	"
6-8	75.36	204	2972	10	14.57	.049	"
1-3	53.24	244	3735	11	15.30	.045	"
3-5	63.24	204	4131	10.9	20.30	.053	"
5-7	73.52	204	4149	10.9	20.30	.053	"
7-9	73.52	204	4149	10.9	20.30	.053	"
3-2	18.2	168	73	5.25	0.43	.031	"
3-4	38.88	244	288	6.38	1.18	.026	"
5-4	14.7	168	288	6.0	1.71	.036	"
5-6	25.0	244	164.8	6.25	0.68	.026	"
6-7	11.8	168	157.4	5.0	0.94	.039	"
7-8	14.42	244	25.9	3.7	0.18	.015	"

Table B 1

Tri-angle	Angle	Factor of cot (1.215)	Factor of cot (.823)	$\Delta\angle$
A...	1	----------	-0 + 16.9	+ 17.9
	2	- 16.9 - 16.85	-16.9 - 0	- 54.8
	3	+ 16.85+ 16.9	----------	+ 40.7
B...	2	23.2 - 16.85	23.2 - 0	+ 27.05
	3	16.85- 23.2	----------	- 7.95
	4	----------	0 - 23.2	- 19.10
C...	3	----------	-38.9 - 23.2	- 51.1
	4	- 22.0 - 23.2	----------	- 54.9
	5	23.2 + 22	23.2 + 38.9	+106.1
D...	4	36 - 22.5	36 + 38.9	+ 78.0
	5	22.5 - 36	----------	- 16.4
	6	----------	-38.9 - 36.0	- 61.6
E...	5	----------	36.2 - 36	+ .1645
	6	- 28.8 - 36	----------	- 78
	7	36 + 28.2	36 - 36.2	+ 77.8355
F...	6	- 46.4 - 27.6	-46.4 - 36.2	-156.0
	7	+ 46.4 + 27.6	----------	+ 90
	8	----------	36.2 + 46.4	+ 68.0
G...	7	----------	0 + 46.4	+ 38.2
	8	- 21.3 + 46.4	----------	+ 30.5
	9	- 46.4 + 21.3	-46.4 - 0	- 68.7
H...	8	- 21.3 - 26.8	----------	- 38.4
	9	+ 21.3 + 26.8	26.8 - 0	+ 80.4
	11	----------	0 - 26.8	- 22
I...	8	----------	-29.1 - 26.8	- 46
	10	26.8 - 16.85	26.8 + 29.1	+ 37.95
	11	16.85- 26.8	----------	- 11.95
J...	10	- 16.5 - 17.2	----------	- 41
	11	17.2 + 16.5	17.2 + 29.1	+ 79.2
	13	----------	-29.1 - 17.2	- 36.2
K...	10	----------	0 - 17.2	- 14.30
	12	17.2 - 12.5	17.2 - 0	+ 19.91
	13	12.5 - 17.2	----------	- 5.71
L...	12	-12.6 - 12.5	-12.6 - 0	- 40.2
	13	12.5 + 12.6	----------	+ 30.6
	14	----------	0 + 12.6	+ 10.4

Table B 2

Tri-angle	Angle	Factor of cot (1.215)	Factor of cot (.823)	dℓ
E...	5	----------	- 48.5 - 36	- 69.5
	6	-28.2 - 36	----------	- 78.0
	7	36 + 28.2	36 + 48.5	+147.5
F...	7	27.6 - 62.4	----------	- 42.3
	6	62.4 - 27.6	62.4 + 48.5	+138.5
	8	----------	- 48.5 - 62.4	- 91.2
G...	7	----------	0 - 62.4	- 51.6
	8	-37.8 - 62.4	----------	-122
	9	62.4 + 37.8	62.4 - 0	+173.4
H...	8	-37.8 - 48	----------	-104
	9	48 + 37.8	48 - 0	+140.6
	11	----------	0 - 48	- 39.6
I...	8	----------	- 51.7 - 48	- 82.2
	10	48 - 29.9	48 + 51.7	+104.9
	11	29.9 - 48	----------	-122
J...	10	-29.2 - 30.8	----------	- 71.9
	11	30.8 + 29.2	30.8 + 51.7	+145.3
	13	----------	- 51.7 - 38	- 68.0
K...	10	----------	0 - 30.8	- 25.4
	12	30.8 - 22.4	30.8 - 0	+ 35.6
	13	22.4 - 30.8	----------	- 10.2
L...	12	-22.5 - 22.4	- 22.5 - 0	- 73.1
	13	22.4 + 22.5	----------	+ 54.6
	14	----------	0 + 22.5	+ 18.5

Table B 3

Tri-angle	Angle	Factor of cot (1.215)	Factor cot (.823)	dL
H...	8	- 37.8 + 36	----------	-2.19
	9	- 36 + 37.8	-36 - 0	-26.41
	11	----------	0 + 36.0	+29.6
I...	8	----------	38.9+ 36	+61.5
	10	- 36 - 56.2	-36 - 38.9	-173.5
	11	56.2 + 36	----------	+112.0
J...	10	- 55.0 - 57.6	----------	-137
	11	57.6 + 55	57.6- 38.9	+152.4
	13	----------	38.9- 57.6	- 15.4
K...	10	----------	0 - 57.6	- 47.4
	12	57.6 - 41.8	57.6- 0	+ 66.6
	13	41.8 - 57.6	----------	- 19.2
L...	12	- 42 - 41.8	-42 - 0	-136.4
	13	41.8 + 42	----------	+101.8
	14	----------	0 + 42.0	+ 34.6

Table B 4

Tri-angle	Angle	Factor of cot (1.215)	Factor cot (.823)	d
J...	10	- 55 + 23.1	----------	- 38.7
	11	- 23.1+ 55	-23.1 - 38.9	- 12.3
	13	----------	38.9 + 23.1	+ 51.0
K...	10	----------	22 + 23.1	+ 37.0
	12	- 23.1-100	-83.1 - 22	-186.5
	13	100 + 23.1	----------	+149.5
L...	12	-101 -100	-101 - 22	-345
	13	100 +101	----------	+244
	14	----------	22 +101	+101

Calculation of $d\angle$ and $\Sigma d\angle$

Table C 1

Calculation of $d\angle$ and $K\Sigma d\angle$

Case 1

Joint	Member	K	Angle	$d\angle$	$\Sigma d\angle$	$K\Sigma d\angle$
1...	1-3	15.30	------	--------	--------	---------
	1-2	10.55	3-1-2	+ 13.90	+ 13.90	+ 146.6
		25.85				
2...	2-1	10.55	------	--------	--------	---------
	2-3	0.43	1-2-3	- 64.60	- 64.60	- 27.8
	2-4	10.55	3-2-4	+ 27.05	- 27.55	-291.0
		21.53				
3...	3-5	20.30	------	--------	--------	---------
	3-4	1.18	5-3-4	- 51.10	- 51.10	- 60.3
	3-2	0.43	4-3-2	- 7.95	- 59.05	- 25.7
	3-1	15.30	2-3-1	+ 40.70	- 18.35	-281.0
		37.21				
4...	4-2	10.55	------	------	------	------
	4-3	1.18	2-4-3	- 19.10	- 19.10	- 22.7
	4-5	1.71	3-4-5	- 54.90	- 74.00	-126.5
	4-6	13.80	5-4-6	+ 78.0	+ 4.00	+ 55.2
		27.24				
5...	5-7	20.30	------	------	------	------
	5-6	0.68	6-5-7	+ .17	+ .17	+ .1
	5-4	1.71	4-5-6	- 18.40	- 18.24	- 27.8
	5-3	20.30	3-5-4	+178.00	+ 89.77	+1820.0
		42.99				
6...	6-4	13.80	------	------	------	------
	6-5	0.68	4-6-5	- 81.80	- 81.80	- 41.6
	6-7	0.94	5-6-7	- 78.00	-159.80	-138.8
	6-8	14.57	7-6-8	-158.00	-317.80	-1630.0
		29.99				
7...	7-9	20.30	------	------	------	------
	7-8	0.18	8-7-9	+ 38.20	+ 38.20	+ 6.8
	7-6	0.94	6-7-8	+ 90.00	+128.20	+120.0
	7-5	20.30	5-7-6	+ 77.84	+206.04	+4180.0
		41.72				
8...	8-6	14.57	------	------	------	------
	8-7	0.18	6-8-7	+ 68.40	+ 68.0	12.3
	8-9	0.94	7-8-9	+ 30.50	+ 98.5	+ 92.2
	8-11	0.68	9-8-11	- 58.40	+ 40.1	+ 27.1
	8-10	13.80	11-8-10	- 46.00	- 5.9	- 81.4
		30.16				
9...	9-11	20.30	------	------	------	------
	9-8	0.94	11-9-8	+ 80.40	+ 80.4	+ 75.8
	9-7	20.30	8-9-7	- 65.70	14.7	+298.0
		41.54				
10...	10-8	13.80	------	------	------	------
	10-11	1.71	8-10-11	+ 97.95	+ 97.95	+ 99.0
	10-13	1.18	11-10-13	- 41.00	+ 56.95	+ 26.0
	10-12	10.55	13-10-12	- 14.20	+ 2.75	+ 29.0
		27.24				
11...	11-13	20.30	------	------	------	------
	11-10	1.71	13-11-10	+ 79.20	+ 79.2	+135.0
	11-8	0.68	8-11-10	- 11.25	+ 67.95	+ 46.4
	11-9	20.30	9-11-8	- 22.00	+ 45.9	+931.0
		42.98				
12...	12-10	10.55	------	------	------	------
	12-13	0.43	10-12-13	+ 15.91	+ 15.91	+ 6.7
	12-14	10.55	13-12-14	- 46.90	- 31.0	-328.0
		21.53				
13...	13-14	18.30	------	------	------	------
	13-12	0.43	14-13-14	+ 36.80	+ 36.8	+ 15.8
	13-10	1.18	10-13-12	- 5.71	+ 31.09	+ 36.5
	13-11	20.30	11-13-10	- 38.20	- 14.41	-292.0
		37.21				
14...	14-12	10.55	------	------	------	------
	14-13	15.3	12-14-13	+ 10.40	+ 10.4	+160.0
		25.85				

Table C 2

Calculation of $d\angle$ and $K\Sigma d\angle$

Case II

Joint	Member	K	Angle	$d\angle$	$\Sigma d\angle$	$K\Sigma d\angle$
	6-4	13.80	------	-------	-------	-------
	6-5	0.68	4-6-5	- 61.60	- 61.60	- 41.5
6...	6-7	0.94	5-6-7	- 78.00	-139.60	-131.0
	6-8	14.57	7-6-8	+133.50	- 6.10	- 89.3
		29.98				
	7-9	20.30	------	-------	------	------
	7-8	0.18	8-7-9	- 51.40	- 51.40	- 9.3

Table C 2

Calculation of $d\angle$ and $K\Sigma d\angle$

Case II

Joint	Member	K	Angle	$d\angle$	$\Sigma d\angle$	$K\Sigma d\angle$
6...	6-4	13.80	------	-------	-------	-------
	6-5	0.68	4-6-5	- 61.60	- 61.60	- 41.5
	6-7	0.94	5-6-7	- 78.00	-139.60	-131.0
	6-8	14.57	7-6-8	+133.50	- 6.10	- 89.3
		29.98				
7...	7-9	20.30	------	-------	-------	------
	7-8	0.18	8-7-9	- 51.40	- 51.40	- 9.3
	7-6	0.94	6-7-8	- 42.30	- 93.70	- 87.6
	7-5	20.30	5-7-6	+147.50	+ 53.80	1090.6
		41.72				
8...	8-6	14.57	------	------	------	------
	8-7	0.18	6-8-7	- 91.20	- 91.20	- 16.4
	8-9	0.94	7-8-9	-122.00	-213.20	-199.0
	8-11	0.68	9-8-11	-104.00	-317.20	-214.0
	8-10	13.8	11-8-10	- 82.20	-399.40	-5500.0
		30.16				
9...	9-11	20.30	------	------	------	------
	9-8	0.94	11-9-8	+143.50	+143.50	+134.0
	9-7	20.30	8-9-7	+173.40	+316.90	+6440.9
		41.54				
10...	10-8	13.80	------	------	------	------
	10-11	1.71	8-10-11	+104.20	+104.20	+ 178.5
	10-13	1.16	11-10-13	- 72.90	+ 31.30	+ 37.0
	10-12	10.55	13-10-12	- 25.40	+ 5.90	+ 62.3
		27.24				
11...	11-13	20.3	------	------	------	------
	11-10	1.71	13-11-10	+140.90	+140.90	+ 241.0
	11-8	0.675	8-11-10	- 22.00	+118.90	+ 80.2
	11-9	20.3	9-11-8	- 39.50	+ 79.40	+1610.0
		42.98				
12...	12-10	10.55	------	------	------	------
	12-13	0.434	10-12-13	+ 35.60	+ 35.60	+ 15.5
	12-14	10.55	13-12-14	- 73.10	- 37.50	- 396.0
		21.5				
13...	13-14	15.3	------	------	------	------
	13-12	0.434	12-13-12	+ 54.60	+ 54.60	+ 23.7
	13-10	1.16	10-13-12	- 10.80	+ 44.40	+ 52.4
	13-11	20.3	11-13-10	- 68.00	- 23.60	- 479.0
		37.21				
14...	14-12	10.55	------	------	------	------
	14-13	15.3	12-14-13	+ 18.50	+ 18.50	+ 283.0
		25.85				

Table C 3

Calculation of $d\angle$ and $K\Sigma d\angle$

Case III

Joint	Member	K	Angle	$d\angle$	$\Sigma d\angle$	$K\Sigma d\angle$
	8-6	14.57	------	-------	-------	------
	8-7	0.18	6-8-7	- 91.20	- 91.20	- 16.4
8...	8-9	0.94	7-8-9	-122.00	-213.20	-199.5
	8-11	0.68	9-8-11	- 2.19	-215.39	-145.0
	8-10	13.80	11-8-10	+ 61.50	-153.89	-8120.0
		30.16				
	9-11	20.30	------	------	------	------
9...	9-8	0.94	11-9-8	- 26.41	- 26.41	- 24.7
	9-7	20.30	8-9-7	+173.40	+147.00	+8980.0
		41.54				
	10-8	13.8	------	------	------	------
	10-11	1.71	8-10-11	-173.50	-173.50	- 297.0
10...	10-13	1.18	11-10-13	-137.00	-310.50	- 366.0
	10-12	10.58	13-10-12	- 47.40	-357.90	-3780.0
		27.24				
	11-9	20.30	------	------	------	------
11...	11-10	1.71	13-11-10	+152.40	+152.40	+ 260.0
	11-8	0.68	8-11-10	+ 113.00	-264.40	-179.8

Table C 3

Calculation of d_1 and $K\Sigma d\angle$

Case III

Joint	Member	K	Angle	$d\angle$	$\Sigma d\angle$	$K\Sigma d\angle$
8...	8-6	14.57	------	-------	-------	------
	8-7	0.18	6-8-7	- 91.20	- 91.20	- 16.4
	8-9	0.94	7-8-9	-122.00	-213.20	-196.5
	8-11	0.68	9-8-11	- 3.19	-215.39	-146.0
	8-10	13.80	11-8-10	+ 61.50	+153.89	+8120.6
		30.16				
9...	9-11	20.30	------	-------	-------	------
	9-8	0.94	11-9-8	- 26.41	- 26.41	- 24.7
	9-7	20.30	8-9-7	+173.40	+147.00	+8980.0
		41.54				
10...	10-8	13.8	------	-------	-------	------
	10-11	1.71	8-10-11	-173.50	-173.50	- 297.0
	10-13	1.18	11-10-13	-137.00	-310.50	- 366.0
	10-12	10.55	13-10-12	- 47.40	-357.90	-3780.0
		27.24				
11...	11-13	20.30	------	-------	-------	------
	11-10	1.71	13-11-10	+152.40	+152.40	+ 260.0
	11-8	0.68	8-11-10	+ 112.00	+264.40	+ 178.0
	11-9	20.30	9-11-8	+ 29.60	+294.00	+5970.0
		42.98				
12...	12-10	10.55	------	-------	-------	------
	12-13	0.43	10-12-13	+ 66.60	+ 66.60	+ 28.9
	12-14	10.55	13-12-14	-136.40	- 69.80	- 736.0
		21.53				
13...	13-14	15.30	------	-------	-------	------
	13-12	0.43	12-13-14	+101.80	+101.80	+ 44.8
	13-10	1.18	10-13-12	- 19.20	- 82.60	+ 97.5
	13-11	20.30	11-13-10	- 15.40	+ 67.20	1365.0
		37.21				
14...	14-12	10.55	------	-------	-------	------
	14-13	15.30	12-14-13	+ 34.60	+ 34.60	+ 530.0
		25.85				

Table C 4

Calculation of $d\angle$ and $K\Sigma d\angle$

Case IV

Joint	Member	K	Angle	$d\angle$	$\Sigma d\angle$	$K\Sigma d\angle$
10...	10-8	13.80	------	-------	-------	------
	10-11	1.71	8-10-11	-173.50	-173.50	- 297.0
	10-13	1.18	11-10-13	- 38.70	-212.20	- 250.0
	10-12	10.55	13-10-12	+ 37.00	-175.20	-1850.0
		27.24				
11...	11-13	20.30	------	-------	-------	------
	11-10	1.71	13-11-10	- 12.30	- 12.30	- 21.0
	11-8	0.68	8-11-10	+112.00	+ 99.70	+ 67.3
	11-9	20.30	9-11-8	+ 29.60	+129.30	+2620.0
		42.98				
12...	12-10	10.55	------	------	------	------
	12-13	0.43	10-12-13	-186.50	-186.50	- 81.0
	12-14	10.55	13-12-14	-345.00	-531.50	-5600.0
		21.53				
13...	13-14	15.30	------	------	------	------
	13-12	0.43	12-13-14	+244.00	+244.00	+ 106.0
	13-10	1.18	10-13-12	+149.50	+393.50	+ 464.0
	13-11	20.30	11-13-10	+ 51.00	+444.50	+9000.0
		37.21				
14...	14-12	10.55	------	------	------	------
	14-13	15.30	12-14-13	+101.00	+101.00	+1545.0
		25.85				

Table D

Equation for the Solution of T's.

No. of Joint	First Member of Equation													
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}	T_{13}	T_{14}
1	51.70	10.55	15.30											
2	10.55	43.06	.43	10.55										
3	15.30	.43	74.43	1.18	20.30									
4		10.55	1.18	54.48	1.71	13.80								
5			20.30	1.71	85.98	.68	20.30							
6				13.84	.68	59.96	.94	14.57						
7					20.30	.93	83.44	0.18	20.30					
8						14.57	.18	60.32	.94	13.80	.68			
9							20.30	.94	83.08	-----	20.30			
10								13.80	-----	54.48	1.71	10.55	1.18	
11								.68	20.30	1.71	85.96	-----	20.13	
12										10.55	-----	43.06	.43	10.55
13										1.18	20.30	.43	74.42	15.30
14												10.55	15.30	51.70

Table D (continued)

No. of Joint	Absolute Terms			
	Case I	Case II	Case III	Case IV
1	- 12.2			
2	+ 503.3			
3	-1039.7			
4	+ 567.1			
5	-7606.5	- 4606.8		
6	+8832.1	+ 555.9		
7	-8753.5	- 8289.0		
8	+4102.2	+11744.1	4905.0	
9	-1638.6	-14559.0	-11682.1	
10	- 378.9	+ 4651.0	+10648.5	6571.0
11	-2054.9	- 3347.9	-13739.0	-13890.6
12	+ 384.5	- 908.9	+ 5150.0	+13106.0
13	+ 271.3	+ 470.4	- 3206.3	-20354.0
14	- 96.0	- 962.0	- 324.0	+ 2510.0

THE UNKNOWN TERMS OF EACH EQUATION ARE KEPT IN THE UPPER PART OF THE SHEET; THE ABSOLUTE TERMS OF EACH CORRESPOND. EQUATION ARE ON THE LOWER PART.

TABLE 3

Solution of T's

T's	Case I Load of 1000 lbs. at (6)			Case III Load of 2000 lbs. at (10)			Case IV Load of 4000 lbs. at (12)		
	First Trial	Second Trial	Third Trial	First Trial	Second Trial	Third Trial	First Trial	Second Trial	Third Trial
T_1	- .24	+ 1.49	- 4.84	- .24	+ 1.49	- 1.98	- .24	+ 1.49	- 1.98
T_2	+ 11.80	+ 9.00	+ 19.20	+ 11.80	+ 9.00	+ 10.30	+ 11.80	+ 9.00	+ 10.30
T_3	- 14.00	+ 9.37	+ 5.46	- 14.00	- .33	- 5.80	- 14.00	- .33	- 5.80
T_4	+ 10.50	- 26.00	- 26.6	+ 10.50	+ 8.00	+ 15.85	+ 10.50	+ 8.00	+ 15.85
T_5	+ 87.50	- 66.60	- 73.10	- 52.40	- 29.20	- 37.60	- 52.40	- 29.20	- 37.60
T_6	+147.00	+139.00	+144.00	+ 9.28	- 10.40	- 3.54	+ 9.28	- 10.40	- 7.80
T_7	-105.00	- 73.60	- 89.70	- 99.40	- 58.40	- 69.20	- 99.40	- 58.30	- 69.10
T_8	+ 68.00	+ 36.90	+ 33.80	+ 81.30	+ 43.20	+ 47.00	+ 81.30	+ 16.80	+ 72.50
T_9	- 19.70	+ 3.65	- 3.56	-140.50	- 87.00	- 92.50	-140.50	- 87.50	-103.80
T_{10}	- 6.95	- 3.04	- 18.10	+196.00	+167.50	+169.50	+119.00	+ 56.70	+ 53.90
T_{11}	- 23.90	+ 22.0	- 23.50	-160.00	-130.50	-142.50	-161.80	- 74.70	- 75.00
T_{12}	+ 8.95	+ 9.65	+ 14.15	+119.50	+ 94.40	+ 84.40	+304.00	+282.00	+273.00
T_{13}	+ 3.64	- 1.99	+ 10.90	- 43.20	+ 2.20	- 41.30	-287.00	-265.00	-256.00
T_{14}	- 1.86	- 3.24	- 7.84	- 6.27	- 26.20	- 11.25	+ 48.50	+ 69.30	+ 68.00

Table 7

Joint	Member	$\frac{c}{c}$	Case I Load at 6 Load = 1000 lbs.			Case III Load at 10 Load = 1000 lbs.			Case IV Load at 12 Load = 1000 lbs.		
			T	$\Sigma T_{mn} + T_{nm}$	f	T	$\Sigma T_{mn} + T_{nm}$	f	T	$\Sigma T_{mn} + T_{nm}$	f

Joint	Member	c / l	Case I Load at 6 Load = 1000 lbs. T	$\frac{E}{2}m_1 \cdot m_2 \cdot \frac{m}{m}$	f	Case III Load at 10 Load = 1000 lbs. T	$\frac{E}{2}m_1 \cdot m_2 \cdot \frac{m}{m}$	f	Case IV Load at 12 Load = 1000 lbs. T	$\frac{E}{2}m_1 \cdot m_2 \cdot \frac{m}{m}$	f
	1-3	.040	- 4.84	- 22.37	- 2.03 -	1.98	- 28.11	- 1.26 -	1.98	- 28.11	- .63
1...	1-5	.041	- 4.84	- 22.37	+ 1.85 +	1.98	+ 28.11	+ 1.15 +	1.98	+ 28.11	+ .58
	1-2	.047	9.14	+ 37.44	- 3.68 +	11.92	+ 34.14	+ 1.67 +	11.92	+ 34.14	+ .84
	2-1	.049	19.20	+ 47.34	+ 4.67 +	10.30	+ 32.52	+ 1.59 +	10.30	+ 32.52	+ .79
2...	2-3	.0318	-38.40	-124.39	- 7.71 -	44.30	-153.35	- 4.75 -	44.30	-153.35	- 2.38
	2-4	.049	- 8.55	- 43.3	- 4.38 -	17.25	- 18.65	- .90 -	17.25	- 18.65	- .45
	3-1	.041	-12.80	- 30.8	- 2.50 -	24.15	- 56.28	- 2.06 -	24.15	- 56.28	- 1.03
	3-1	.145	-12.80	- 30.8	+ 2.70 +	24.15	+ 56.28	+ 2.26 +	24.15	+ 56.28	+ 1.13
	3-2	.031	-53.60	-142.6	- 8.84 -	64.52	-174.00	- 5.40 -	64.85	-174.00	- 2.70
3...	3-4	.026	-45.64	-136.9	- 7.07 -	56.90	-107.05	- 2.79 -	56.90	-107.05	- 1.39
	3-5	.053	+ 5.46	+ 27.59	+ 2.92 +	8.90	+ 40.57	+ 2.15 -	5.80	+ 40.57	+ 1.08
	3-5	.049	5.46	+ 27.59	- 2.70 -	8.90	+ 40.57	- 1.95 -	5.80	+ 40.57	- 0.98
	4-2	.049	-26.60	- 61.80	- 6.05 +	15.85	- 24.45	- 1.20 +	15.85	- 24.45	- .60
	4-3	.026	-45.70	-137.30	- 7.11 -	3.85	- 63.40	- 1.65 +	3.25	- 63.40	- .83
4...	4-5	.036	-100.60	-290.50	- 20.90 -	58.15	-170.14	- 6.12 -	58.15	-170.14	- 3.06
	4-6	.049	- 22.60	+ 98.80	+ 9.70 +	19.35	+ 38.16	+ 1.77 +	19.85	+ 31.92	+ .78
	5-3	.053	- 16.70	- 28.00	- 2.77 -	52.17	-110.14	- 3.85 +	52.10	+ 98.40	+ 2.66
	5-3	.049	- 16.70	- 28.00	+ 2.74 +	52.17	-110.14	+ 8.40 +	52.10	+ 98.40	+ 2.46
	5-4	.036	- 86.3	-279.8	- 20.10 -	53.34	-165.33	- 5.95 -	53.84	-175.80	- 3.16
5...	5-6	.026	- 73.00	- 63.60	- 3.31 -	37.50	-140.14	- 2.64 -	37.50	-144.3	- 1.87
	5-7	.053	- 73.10	- 29.90	- 3.32 -	37.60	- 90.60	- 4.90 -	37.60	- 90.6	- 2.40
	5-7	.049	- 73.10	- 29.90	+ 2.93 -	37.60	- 90.60	+ 4.45 -	37.60	- 90.6	+ 2.22
	6-4	.047	+144.00	+285.40	+ 26.00 -	8.54	+ 12.77	+ .63 -	7.80	+ 4.25	+ .11
	6-5	.026	+ 82.40	+ 91.80	+ 47.70 -	68.14	-167.78	- 4.36 -	69.40	-176.30	- 2.29
6...	6-7	.030	+ 4.40	+ 47.30	- 5.84 -	143.14	-449.18	- 13.50 -	147.40	-449.66	- 6.75
	6-8	.049	-153.60	-273.40	- 26.80 -	9.64	+ 27.78	+ 1.08 -	13.9	+ 44.70	+ 1.12
	7-5	.053	+116.30	+159.90	+ 16.90 -	15.40	- 69.40	- 3.70 -	15.30	- 68.20	- 1.84
	7-5	.049	+116.30	+159.90	+ 16.60 -	15.40	- 68.40	+ 3.35 -	15.30	- 68.20	+ 1.70
	7-6	.030	+ 38.50	+ 81.40	- 4.88 -	162.90	-468.94	- 14.00 -	163.80	-473.00	- 7.10
7...	7-8	.016	- 51.50	- 1.80	- .04 -	120.60	-285.40	- 4.57 -	120.50	-259.70	- 2.07
	7-9	.053	- 39.70	-194.70	- 20.00 -	69.20	- 83.90	- 4.53 -	69.1	- 96.0	- 3.52
	7-9	.049	- 39.70	-194.70	+ 19.10 -	69.20	- 83.90	+ 4.10 -	69.1	- 96.00	+ 3.33
	8-6	.049	+ 33.30	- 86.00	- 8.44 +	47.00	+ 84.36	+ 4.13 +	72.50	+131.10	+ 3.23
	8-7	.016	101.80	+152.10	+ 4.86 -	44.20	-209.00	- 3.34 -	18.70	-167.50	- 1.67
8...	8-9	.030	+132.30	+341.40	+ 20.40 -	166.20	-451.31	- 13.50 -	140.70	-410.81	- 6.15
	8-11	.026	+ 73.90	+179.50	+ 9.33 -	168.39	-214.88	- 5.55 -	142.90	- 99.40	- 1.22
	8-10	.049	+ 27.90	+ 37.70	+ 3.70 -	106.89	- 44.28	- 2.17 -	81.40	-108.90	- 2.70
	9-7	.053	- 8.10	- 73.50	- 7.80 +	54.50	+ 39.50	+ 2.11 +	43.20	+ 17.30	+ .47
	9-7	.049	- 8.10	- 73.50	+ 7.20 +	54.50	+ 29.80	- 1.95 +	43.20	+ 17.30	- .43
9...	9-8	.030	+ 76.90	+286.20	+ 17.10 -	118.91	-404.02	- 12.15 -	130.21	-401.00	- 6.00
	9-11	.049	- 3.56	+ 11.60	+ 1.14 -	92.50	- 33.50	- 1.64 -	103.80	+ 11.40	+ .29
	9-11	.053	- 3.56	+ 11.60	- 1.23 -	92.50	- 33.50	+ 1.78 -	103.80	+ 11.40	- .31
	10-8	.049	- 18.10	- 8.30	- .84 +	169.50	+232.10	+ 11.40 +	53.50	+ 25.60	+ .64
	10-11	.036	+ 39.85	+138.40	+ 9.75 -	4.00	0	0	-119.6	-161.80	- 2.91
10...	10-13	.026	- 1.15	+ 33.39	+ 1.74 -	201.00	+360.70	+ 9.35 -	256.60	-686.00	- 8.90
	10-12	.049	- 15.35	- 16.55	- 1.62 -	188.40	-292.40	- 14.30 -	304.00	-331.00	- 8.26
	11-13	.053	- 23.50	- 29.50	- 3.13 -	142.50	-259.10	- 13.70 -	75.00	-338.00	- 9.12
	11-13	.049	- 23.50	- 29.50	+ 2.89 -	142.50	-259.10	+ 12.70 -	75.00	-338.00	+ 8.45
	11-10	.036	+ 55.70	+151.25	+ 10.90 +	16.00	+ 16.00	+ .58 +	77.40	+ 35.20	+ .63
11...	11-8	.026	+ 43.75	+161.40	+ 8.38 +	121.90	+ 76.40	+ 1.96 +	189.40	+235.90	+ 3.06
	11-9	.053	+ 21.75	+ 40.00	+ 4.23 +	151.50	+210.50	+ 11.10 +	219.00	+334.20	+ 9.03
	11-9	.049	+ 21.75	+ 40.00	+ 3.92 +	151.50	+210.50	+ 10.30 +	219.00	+334.20	+ 8.35
	12-10	.049	+ 14.15	+ 12.95	+ 1.37 +	84.40	+ 19.80	+ .96 +	277.00	+250.00	+ 6.25
12...	12-13	.031	+ 34.06	+109.52	+ 6.78 +	151.00	+362.00	+ 11.20 +	343.60	+533.00	+ 8.54
	12-14	.049	- 6.96	- 21.54	- 2.11 +	14.60	+ 17.95	- .97 +	207.20	+482.40	+ 12.2
	13-14	.045	+ 10.90	+ 24.36	+ 2.19 -	41.30	- 59.25	- 2.66 -	256.00	-409.00	- 9.40
	13-14	.041	+ 10.90	+ 24.36	+ 2.00 -	41.30	- 59.25	+ 2.43 -	256.00	-409.00	+ 8.55
	13-12	.031	+ 41.40	+116.86	+ 7.25 +	60.50	+272.00	+ 8.42 +	154.80	+ 34.60	+ .55
13...	13-10	.026	+ 38.69	+ 70.23	+ 3.65 +	41.30	+118.40	- 3.08 -	173.6	- 90.60	- 1.18
	13-11	.053	- 2.51	- 18.48	+ 1.96 +	26.30	- 89.90	- 4.77 -	184.80	-452.60	- 12.20
	13-11	.049	- 2.51	- 18.48	- 1.81 +	26.70	- 89.90	+ 4.40 -	188.80	-452.60	+ 11.30
	14-12	.049	- 7.84	- 22.53	- 2.20 -	11.25	- 7.9	- .30 +	68.00	+343.00	+ 8.57
14...	14-13	.045	+ 2.56	+ 16.02	+ 1.44 +	23.35	+ 5.4	+ .24 +	102.60	- 50.8	- 1.17
	14-13	.041	+ 2.56	+ 16.02	- 1.31 +	23.35	+ 5.4	- .22 +	102.60	- 50.8	+ 1.07

Table G

Member		Secondary Stresses for Load at						Max. Prin. Stress	Total Second. Stress	Percent Second. of
		2	4	6	8	10	12		For Max. Prin. Ch.	Max. Prin.
End Post	1-3 T	- 1.17	+ .24	- 2.08	+ 1.44	- 1.26	- .63		- 3.41	5.2%
	B	+ 1.07	- .22	+ 1.85	- 1.31	+ 1.15	+ .58			
	3-1 B	- 9.40	- 2.66	- 2.50	+ 2.19	- 2.06	- 1.03	- 66.3	-15.46	23.3%
	T	+ 8.60	+ 2.43	+ 2.70	- 2.00	+ 2.26	+ 1.13			
Top Chords	3-5 T	-12.20	- 4.77	+ 3.92	+ 1.96	+ 2.15	+ 1.08		- 8.86	9.3%
	B	+11.30	+ 4.40	- 2.70	- 1.81	- 1.95	- .98	- 95.1		
	5-3 T	- 9.12	-13.70	- 2.97	- 3.10	- 3.95	+ 2.66		-32.20	33.8%
	B	+ 8.45	+12.7	+ 2.74	+ 2.89	+ 3.40	- 2.46			
	5-7 T	+ 9.03	+11.10	- 3.32	+ 4.20	- 4.30	- 2.40		+13.84	13.8%
	B	- 8.35	-10.30	+ 2.93	- 3.92	+ 4.45	+ 2.22	-100.5		
	7-5 T	+ .31	- 1.78	+16.90	+ 1.23	- 3.70	- 1.84		+11.12	11.1%
	B	- .29	+ 1.64	-15.60	- 1.14	+3.35	+ 1.70			

Table 6

Member		Secondary Stresses [illegible] 1000 at						Max. Prim. Stress	Total Secon. Stress	Percent Second. of
		2	4	6	8	10	12		For Max. Prim. St.	Max. Prim.
[illegible] Post	1-3 T	- 1.17	+ .24	- 2.03	+ 1.44	- 1.26	- .63		- 3.41	5.2%
	B	+ 1.07	- .22	+ 1.85	- 1.31	+ 1.15	+ .58			
	3-1 B	- 9.40	- 2.66	- 2.30	+ 2.19	- 2.06	- 1.03	- 66.3	-13.46	23.3%
	T	+ 8.60	+ 2.43	+ 2.70	- 2.00	+ 2.26	+ 1.13			
Top Chords	3-5 T	-12.20	- 4.77	+ [illegible]92	+ 1.96	+ 2.15	+ 1.08		- [illegible]	[illegible]%
	B	+11.30	+ 4.40	- 2.70	- 1.81	- 1.95	- .98	- 96.1		
	5-3 T	- 9.12	-13.70	- 2.97	- 3.13	- 5.95	+ 2.66		-[illegible]	[illegible]%
	B	+ 8.45	+12.7	+ 2.74	+ 2.89	+ 5.40	- 2.46			
	5-7 T	+ 9.03	+11.10	- 3.32	+ 4.23	- 4.80	- 2.40		+[illegible]	13.8%
	B	- 8.35	-10.30	+ 2.93	- 3.92	+ 4.45	+ 2.22	-100.5		
	7-5 T	+ .31	- 1.78	+16.90	+ 1.23	- 3.70	- 1.84		+[illegible]	11.1%
	B	- .29	+ 1.64	-15.60	- 1.14	-13.35	+ 1.70			
	7-9 T	+ .47	+ 2.11	-20.60	- 7.80	- 4.53	- 3.52		-[illegible]	41.2%
	B	- .43	- 1.95	+19.10	+ 7.20	+ 4.10	+ 3.33			
	9-7 T	- 3.52	- 4.53	- 7.80	-20.60	+ 2.11	+ .47	- 88.30	-[illegible]	41.2%
	B	+ 3.33	+ 4.10	+ 7.20	+19.10	- 1.95	- .43			
Bottom Chords	1-2	+ 8.57	- .30	+ 3.68	- 2.80	+ 1.67	+ .84	+ 88.1	+16.43	18.7%
	2-1	+12.20	+ .87	+ 4.67	- 2.11	+ 1.59	+ .79			
	2-4	+ 6.25	+ .96	- 4.35	+ 1.27	- .90	- .45	+ 88.1	-32.03	36.4%
	4-2	- 8.26	-14.30	- 6.05	- 1.62	- 1.20	- .60			
	4-6	+ .64	+11.40	+ 9.70	- .84	+ 1.77	+ .78	+ 98.9	+25.57	25.8%
	6-4	- 2.70	- 2.17	+26.0	+ 3.70	+ .63	+ .11			
	6-8	+ 3.28	+ 4.13	-26.80	- 8.44	+ 1.08	+ 1.12	+ 90.2	+25.63	28.4%
	8-6	+ 1.12	+ 1.08	- 8.44	-26.80	+ 4.13	+ 3.28			
Hip Vertical	3-2	+ .57	+ 8.42	- 8.84	+ 7.25	- 5.40	- 2.70	+ 56.00	- .7	1.2%
	2-3	+ 8.54	+11.20	- 7.71	+ 6.78	- 4.75	- 2.38		+11.68	20.00%
Second Vertical	5-4	+ .64	+ .58	-20.10	+10.90	- 5.95	- 3.16	-127.3	-17.09	13.4%
	4-5	+ 2.91	0	-20.90	+ 9.75	- 6.12	- 3.06		-17.42	13.7%
Middle Vertical	7-6	- 6.00	-12.15	+ 4.88	+17.10	-14.00	- 7.10	- 48.9	-17.27	35.3%
	6-7	- 6.15	-13.50	+ 2.84	+20.40	-13.50	- 6.75		-16.66	34.0%
First Diagonal	3-4	- 1.18	- 3.08	- 7.27	+ 3.65	- 2.79	- 1.39	+ 52.6	-11.86	22.6%
	4-3	- 8.90	+ 9.35	- 7.11	+ 1.74	- 1.65	- .83		- 7.40	14.1%
Second Diagonal	5-6	- 3.06	+ 1.96	- 3.31	+ 8.38	- 2.64	- 1.87	+ 62.5	+ 6.58	10.5%
	6-5	- 1.22	- 5.55	+ 4.77	+ 9.33	- 4.36	- 2.29		+ .68	1.1%
Third Diagonal	7-8	+ 2.07	+ 4.57	- .04	+ .04	- 4.57	- 2.07	0	0	0
	8-7	+ 1.27	+ 3.34	- 4.96	- 4.86	- 3.34	- 1.27		0	0

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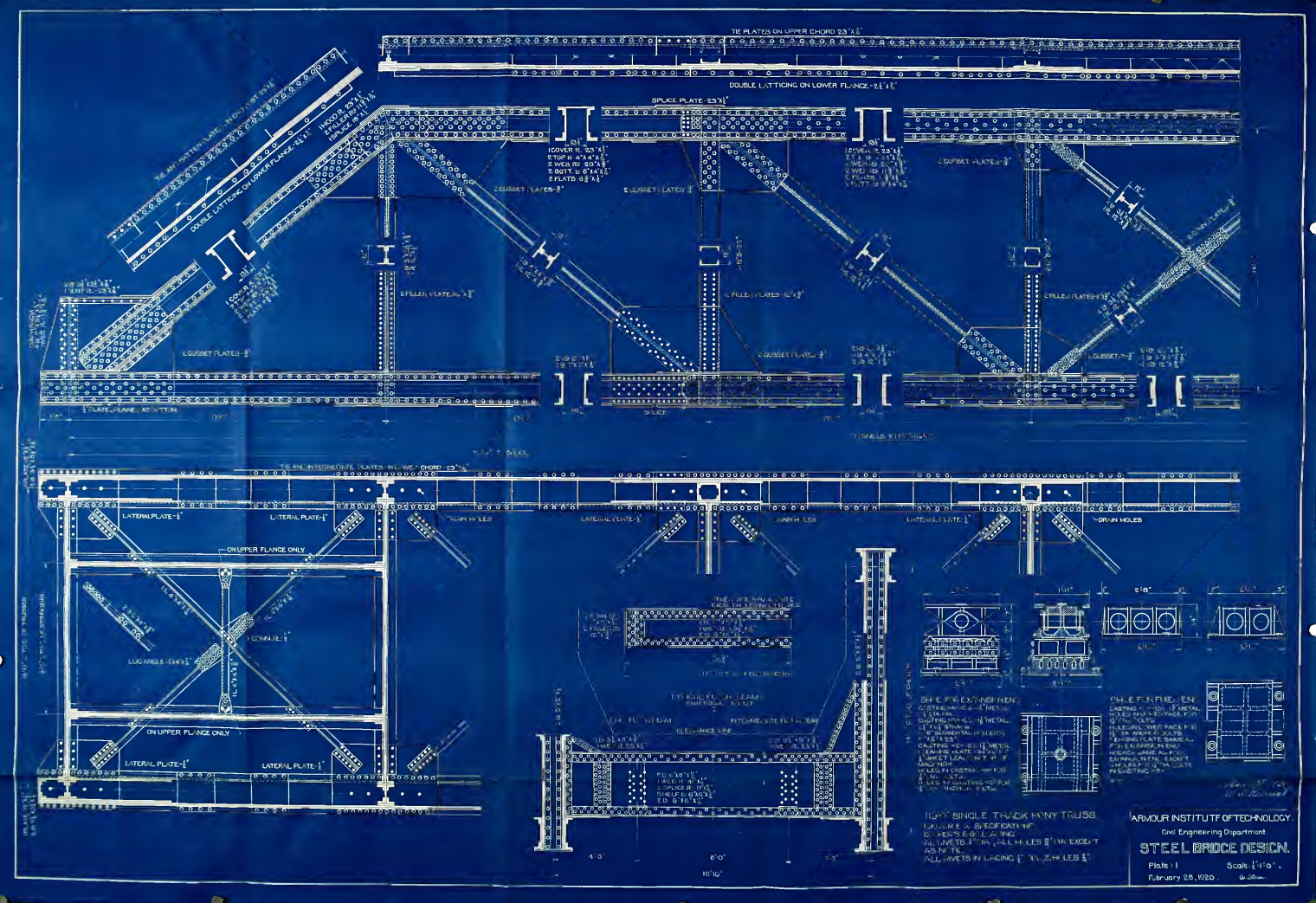
Plate : I

February 28


TIE PLATES ON UPPER CHORD 23"x⅜"
DOUBLE LATTICING ON LOWER FLANGE-22"x⅜"
SPLICE PLATE-23"x⅜"
COVER PL 23"x⅜"
2 TOP L's 4"x4"x⅜"
2 WEB PLS 20"x⅜"
2 BOTT L's 6"x4"x⅜"
2 FLATS 9"x⅜"
GUSSET PLATES-⅜"
FILLER PLATES-½"
LATERAL PLATE-⅜"
ON UPPER FLANGE ONLY
ON LOWER FLANGE ONLY
TIE PLATES-INTERMEDIATE PLATES ALL WEB CHORD-23"x⅜"
DRAIN HOLES
LUG ANGLE-5"x3½"x⅜"
SHOE FOR EXPANSION END
SHOE FOR FIXED END
LIGHT SINGLE TRACK PONY TRUSS
ARMOUR INSTITUTE OF TECHNOLOGY
Civil Engineering Department
STEEL BRIDGE DESIGN.
Plate: I
Scale: 1"=1'0"
February 28, 1920.